

IOWA STATE UNIVERSITY

Digital Repository

Graduate Theses and Dissertations

Iowa State University Capstones, Theses and
Dissertations

2008

Effects of geometric shape and serving temperature on quality characteristics of irradiated bologna and frankfurters

Adam L. Krause
Iowa State University

Follow this and additional works at: <https://lib.dr.iastate.edu/etd>

 Part of the [Animal Sciences Commons](#)

Recommended Citation

Krause, Adam L., "Effects of geometric shape and serving temperature on quality characteristics of irradiated bologna and frankfurters" (2008). *Graduate Theses and Dissertations*. 10986.
<https://lib.dr.iastate.edu/etd/10986>

This Thesis is brought to you for free and open access by the Iowa State University Capstones, Theses and Dissertations at Iowa State University Digital Repository. It has been accepted for inclusion in Graduate Theses and Dissertations by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.

**Effects of geometric shape and serving temperature on quality characteristics of
irradiated bologna and frankfurters**

by

Adam L. Krause

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Meat Science

Program of Study Committee:
Dennis Olson, Major Professor
Joe Sebranek
Aubrey Mendonca

Iowa State University

Ames, Iowa

2008

TABLE OF CONTENTS

Chapter 1. GENERAL INTRODUCTION	1
Thesis Organization	2
CHAPTER 2. REVIEW OF LITERATURE	3
What is Irradiation?	3
History of Irradiation	5
Current Status of Irradiation	7
Consumer Acceptance of Irradiation	9
Justification for Irradiation of Ready-To-Eat Meats	11
Mechanism of Microbial Reduction	13
Factors Affecting Radiation Sensitivity of Microorganisms	16
Effect of Irradiation on <i>Listeria</i> in Ready-To-Eat meats	19
Quality Changes in Processed Meats by Irradiation	20
Color Changes due to Irradiation	21
Lipid Oxidation production of Irradiated Processed Meats	22
Off-Odor Production of Irradiated Processed Meats	25
Off-Flavor Production of Irradiated Processed Meats	26
Summary	27
References	28
CHAPTER 3. EFFECTS OF GEOMETRIC SHAPE AND SERVING TEMPERATURE ON QUALITY CHARACTERISTICS OF IRRADIATED BOLOGAN AND FRANKFURTERS	34
Abstract	34
Introduction	34
Materials and Methods	36
Raw Materials	36
Bologna and Frankfurter Production	37
Irradiation	40
pH Analysis	41
Fat, Moisture, and Protein Analysis	41
Lipid Oxidation	41
Color Analysis	42
Texture	43
Sensory Analysis	43
Statistical Analysis	46
Results	46
Cold Product	48
Hot Product	50
Discussion	51
Conclusion	53
References	53

CHAPTER 6. GENERAL CONCLUSIONS	64
ACKNOWLEDGEMENTS	66

CHAPTER 1. GENERAL INTRODUCTION

Introduction

The increased need for the meat industry to achieve control of pathogenic microorganisms has become painfully obvious in the large-volume recalls of meat products that have recently occurred. Recalls have been most often due to *Escherichia coli* 0157:H7 contamination in ground beef and to *Listeria monocytogenes* contamination of ready-to-eat products such as frankfurters and bologna. The meat industry has responded to the problems in ground beef by increased utilization of low-dose irradiation to eliminate *E. coli* 0157:H7. However, cured, cooked products such as frankfurters and bologna have not yet been approved for irradiation processing. It is very likely, given the current concern over *L. monocytogenes* in ready-to-eat (RTE) products, that irradiation will be permitted for RTE products in the near future.

Even with the approval of irradiation, questions still remain concerning potential quality changes that may occur. The most effective means of controlling *L. monocytogenes* in RTE meat products would be post-packaging irradiation. The concern with this is any changes that may occur from the irradiation process, especially in odors or flavors, are likely to be retained in the closed package and experienced by consumers. Research on irradiation of RTE products has been inconclusive in terms of quality effects with some reports suggesting that undesirable odor changes occur with irradiation, and subsequently dissipate with time or when the product is heated. Other reports have suggested that relatively little undesirable change occurs in RTE products as a result of irradiation. It appears that quality changes in irradiated RTE processed meat are sporadic which suggests that the causes and the means of control are not well understood.

A very interesting recent observation has been that identical all-beef emulsion formulations, placed in two different physical shapes, resulted in different quality effects. Specifically, it has been claimed that an all-beef frankfurter formulation resulted in minimal quality change when irradiated, but that the identical all-beef formulation in sliced bologna form resulted in significant undesirable odor changes. There are several differences in these two products despite an identical meat-seasoning-cure blend. One such difference is the difference in physical shape of a stack of bologna slices compared to frankfurter links. Therefore, the objective of this research was to determine the effect of physical shape on quality characteristics of irradiated frankfurters and bologna as well as the effects of irradiation on these products' quality attributes.

Thesis Organization

This thesis is organized into four chapters. The first chapter is a general introduction to the irradiation of processed meat products. The second chapter is a general literature review of relevant topics pertaining to this research. The third chapter is a manuscript to be submitted to the Journal of Meat Science. The manuscript contains an abstract, introduction, materials and methods, results and discussion, conclusion, and references. The fourth chapter is a general summary of this research.

CHAPTER 2. REVIEW OF LITERATURE

What is Irradiation

Radiation can be defined by the physical phenomenon in which energy travels through space or matter (Olson, 1995). Common forms of this radiation we encounter are visible light, microwaves, infrared, ultraviolet and X-rays. Irradiation refers to the exposure of these energy waves to a specific material, such as a food product (Satin, 1996). In the case of food irradiation, the most useful form of radiation is ionizing radiation. Ionizing radiation contains amounts of energy large enough to eject electrons from their orbitals forming charged or ionizing particles (Olson, 1995). These reactive ions or free radicals interact with other food chemicals forming stable compounds called radiolytic products (Olson, 1995; Satin, 1996).

The purpose of irradiating food products is to increase the safety and shelf life of foods through the blockage of enzyme activity, elimination of parasites or insects, and the reduction of microorganisms (Andrews et al., 1998). The three main sources of ionizing radiation used in food irradiation are gamma rays, electron beams, and X-rays. Gamma rays are photons produced by radioactive isotopes cesium-137 and cobalt-60 and contain energy of about 1-2 million electron volts (MeV). Since photons have no mass or charge they have the ability to penetrate deep into a material, such as food. Machine accelerated electrons also can be used to irradiate food. These accelerated high energy level electrons (5-10 MeV) differ from photons in that they have mass and charge and therefore cannot penetrate as deeply into materials as gamma rays. Accelerated electrons can also be converted to X-rays when they are made to collide with heavy metals such as tungsten (Olson, 1995).

When ionizing radiation penetrates into a medium such as a food product, all or part of the radiation energy is absorbed by the medium. This is referred to as the absorbed dose (Diehl, 1995). The absorbed dose is dictated by the strength and amount of time of exposure to the irradiation source. The International System of Unit for the absorbed dose is the Gray (Gy). A Gray is equal to the absorption of one joule of energy per kilogram of food (Olson, 1995). Because food products are often irradiated at doses around 1000 Grays, the kilo Gray (kGy) is the more commonly used term. The older unit of radiation measurement is the rad which equals 100 erg of energy absorbed per gram of medium. One Gray equals 100 rad and thus, 1 million rads equals 10,000 Gray, or 10 kilo Gray (Olson, 1995). The general application of food irradiation can be divided into three of the following dose categories (Olson, 1995; Satin, 1996):

(1) Low dose, < 1 kGy

- sprout inhibition
- delay of ripening
- insect disinfestation

(2) Medium dose, 1-10 kGy

- reduction of spoilage microorganisms
- reduction of non-spore-forming pathogens
- delay of ripening

(3) High dose, 10-50 kGy

- sterilization

The dose that is absorbed during irradiation is not easily measured from irradiated products. For that reason, a radiation sensitive material called a dosimeter is irradiated

along with the product. There are two main types of dosimeters used to determine the absorbed dose a product receives, radiochromic films and alanine pellets. Radiochromic films change color during the irradiation process representing the amount of dose the product receives. The color change is then read on a spectrophotometer. The amount of color change represents the absorbed dose the product receives. Alanine pellets form free radicals when exposed to irradiation and the retained free radicals in the pellets can be read using an electron spin resonance spectrometry which represents the absorbed dose (Olson, 1995).

The primary purpose of food irradiation in meat and poultry products is to eliminate or reduce microorganisms in the food product. A measure of a process's ability and efficiency to eliminate or reduce the microbial load is a D-value. In thermal processing, the D-value is the time required, at a specific temperature, to reduce the designated microbial population by 90% or 1 log. In irradiation, the D-value is the dose needed to destroy 90% of the designated microbial population in a given medium (Andrews et al., 1998).

History of Irradiation

The idea of exposing a material to ionizing radiation is over a century old. In 1895, Wilhelm Röntgen discovered X-rays and in 1896 Henri Becquerel announced his discovery of radioactivity (Goresline, 1982). The idea for using this technology in food followed shortly after these discoveries. In 1905, United States and British patents were issued for the proposed use of killing bacteria in food using ionizing radiation. The next application was in 1916 using X-rays to kill insects, eggs and larvae in tobacco leaves in

order to improve the quality and shelf life of cigars (Diehl, 1995; Goresline, 1982; Satin, 1996). Benjamin Schwartz also used X-rays in 1921 to eliminate *Trichinella spiralis* in fresh pork (Schwartz, 1921). However, the X-ray machines available at the time were not powerful enough to treat pork in a commercial setting.

Continued research in the area of food irradiation slowly followed but was limited by the cost and availability of practical ionization sources. X-rays proved to be effective in preserving ground beef but were too expensive to make the technology practical. It wasn't until after World War II that a renewed interest in food irradiation began. The development of the atomic bomb and the ensuing Atomic Age gave scientists access to isotopes as experimental ionization sources when spent-fuel rods from nuclear reactors became available. This quickly led to the realization that food irradiation could become commercially feasible and a flurry of research quickly followed. However, the timing of the new low-cost ionization sources suddenly linked food irradiation with the atomic bomb, despite food irradiation being developed 50 years prior to the discovery of nuclear radiation. It is an association that the two still continue to this day (Satin, 1996).

The United States Army expressed the most interest in irradiation for food preservation stating the successful development of the ionizing radiation food process would improve the acceptability and safety of military field rations (Goresline, 1982). In 1953, President Dwight D. Eisenhower started an "Atoms for Peace" program that aimed at the benefits of using radioisotopes and radiation technology for peaceful uses. The responsibility of this program was given to the Army Quartermaster Corps which after extensive research concluded in 1965 that foods irradiated with doses up to 56 kGy were

safe for human consumption (Diehl, 1995; Goresline, 1982; Olson, 1995; Radomyski, Murano, Olson & Murano, 1994).

At the international level, a joint expert committee was sponsored by the United Nations' Food and Agricultural Organization (FOA), International Atomic Energy Agency (IAEA), and World Health Organization (WHO) with the goal of determining the wholesomeness of irradiated foods. After reviewing more than a decade of research, in 1981, the WHO concluded "*irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard; hence toxicological testing of foods so treated is no longer required*" (WHO, 1981). In 1999, after further review of the research, the joint committee agreed that no upper dose limit of irradiation compromises food safety. The report stated that foods appropriately prepared, packaged and irradiated to high doses under proper conditions to sterilize them should be considered safe (WHO, 1999).

Current Status of Irradiation

The process of applying ionizing radiation to food products is highly regulated. In the United States, the Food and Drug Administration (FDA) regulates all aspects of irradiation such as product usage, dose levels, and product labeling. The FDA also classifies irradiation as a "food additive" rather than a processing aid and has set different regulations for various products and uses. For example, dry or dehydrated spices and seasonings may be irradiated up to a maximum of 30 kGy for the purpose of microbial disinfection. Refrigerated or frozen poultry may be irradiated with a maximum dose of 3.0 kGy while refrigerated or frozen uncooked meat (beef, pork, lamb, and goat) have

been approved at maximum doses of 4.5 kGy and 7.0 kGy, respectively. The FDA has also approved the use of irradiation for the sterilization of frozen packaged meats used solely by National Aeronautics and Space Administration (NASA) for astronauts. The minimum dosage for sterilization of meat products is 44 kGy. More recently, FDA has approved the use of irradiation for fresh iceberg lettuce and fresh spinach at a maximum dose of 4.0 kGy for the purpose of controlling foodborne pathogens and shelf-life extension (FDA, 2008). A complete list of foods approved for irradiation with their approved irradiation dose is listed below in Table 1.

Food	Purpose	Dose
Fresh, non-heated processed pork	Control of <i>Trichinella spiralis</i>	0.3 kGy min. to 1 kGy max
Fresh Foods	Growth and maturation inhibition	1 kGy max
Foods	Arthropod disinfection	1 kGy max
Dry or dehydrated Enzyme preparations	Microbial disinfection	10 kGy max
Dry or dehydrated spices/seasoning	Microbial disinfection	30 kGy max
Fresh or frozen, uncooked poultry products	Pathogen control	3 kGy max
Frozen packaged meats (solely NASA)	Sterilization	44 kGy max
Refrigerated, uncooked meat products	Pathogen control	4.5 kGy max
Frozen uncooked meat products	Pathogen control	7 kGy max
Fresh shell eggs	Control of <i>Salmonella</i>	3.0 kGy max
Seeds for sprouting	Control of microbial pathogens	8.0 kGy max
Fresh or frozen molluscan shellfish	Control of Vibro species and other foodborne pathogens	5.5 kGy max
Fresh iceberg lettuce and fresh spinach	Control of foodborne pathogens, and extension of shelf-life	4.0 kGy max

Table 1. Foods permitted to be irradiated under FDA's regulations (21 CFR 179.26) (FDA, 2008)

The FDA also requires that irradiated products must carry the radura symbol on the label to signify it has been irradiated. The words “Treated with Irradiation” or “Treated by Irradiation” and “Keep Refrigerated” or “Keep Frozen” must be accompanied with the radura symbol on the product label.

Presently, the FDA does not allow the irradiation of Ready-to-Eat meats. In 1999, under the leadership of the Food Products Association (1350 I Street, NW, Suite 300, Washington, DC 20005), a petition was sent to the FDA asking for their permission to extend the use of irradiation of RTE meat and poultry foods. After 9 years, the FDA has still not acted on the petition (O'Bryan, Crandall, Ricke & Olson, 2008).

Consumer Acceptance of Irradiation

Although scientific research about the use of irradiation has been conducted for over a century, consumers' knowledge of irradiation processing is very limited. When faced with the decision to purchase irradiated foods, consumers' education on the subject is the limiting factor for acceptance. Ressurreccion et. al. (1995) reported that of 446 participants in a mail survey, 32.6 % believed irradiated foods contain radioactivity. Another 48.7% were unsure whether or not irradiated foods contained radioactivity. The authors also reported that only 45% of the participants would buy food that was irradiated.

Although consumers' knowledge on irradiation is limited, it has been shown that when exposed to science based information consumers are more willing to purchase irradiated foods. Nayga et. al. (2005) surveyed 484 consumers face-to-face in Texas supermarkets before and after receiving information on irradiation. The respondents were

then given two sets of information. After the first set of information which pertained to the nature and benefits of food irradiation, the percentage of respondents willing to buy irradiated ground beef increased from 50% to 89%. After the second set of information describing the differences between gamma ray and electron beam irradiation was given to the respondents, the percentage willing to buy irradiated ground beef increased again from 89% to 94.3%. In this study, the more information the consumer had, the more positive reactions respondents had for irradiated foods. Fox et al. (2002) used auctions to determine consumers response to positive and negative descriptions of irradiation. As expected, a positive description of irradiated pork increased its value while a negative one decreased its value. However, when consumers received both positive and negative descriptions about irradiation, consumers put a lower value on the irradiated product. The negative descriptions in this study overpowered the positive description even when it was not scientifically written and identified as coming from Food and Water, Inc., a consumer advocacy group.

Johnson et al. (2004) irradiated RTE poultry frankfurters and diced chicken at 1, 2, and 3 kGy comparing them to unirradiated controls for 32 days of refrigerated storage. No differences were seen in overall acceptance, aroma, appearance, color, flavor, juiciness, tenderness, and mouthfeel/texture between irradiated samples and the control for up to 18 days of storage. At 32 days, irradiated samples had higher consumer ratings for overall acceptance, flavor, juiciness, tenderness and mouthfeel. No differences were seen between irradiated samples regardless of their absorbed dose. The diced chicken irradiated at 3 kGy showed a difference only for aroma at day 4 storage when compared

to the control. At day 18, the irradiated samples had higher consumer scores in overall acceptance, flavor, juiciness, tenderness, and mouthfeel.

Justification for Irradiation of Ready-to-Eat Meat Products

Despite recent advances in food technology, food safety continues to be a concern for the food industry. It is estimated that foodborne diseases account for 76 million illnesses, 325,000 hospitalizations and 5000 deaths in the United States each year (Mead et al., 1999). Of these illnesses, the Centers for Disease Control and Prevention (CDC) (2008) estimates 2500 cases of listeriosis occur in the United States each year resulting in 500 deaths. *Listeria monocytogenes*, the organism responsible for listeriosis, is a significant threat to ready-to-eat (RTE) meat products because of its ubiquitous nature, resistance to salt, and its ability to grow at refrigerated temperatures (Zhu, Du, Cordray & Ahn, 2005a). The risk of listeriosis is greatest among certain groups including pregnant women, young children, the elderly and immunocompromised individuals. Since 1989, the United States Department of Agriculture (USDA) has had a “zero tolerance” in effect with regard to *L. monocytogenes* in RTE meat products. Any product testing positive for *L. monocytogenes* is classified as adulterated (USDA, 2003).

Thermal processing effectively controls and kills *L. monocytogenes*, however, food recalls of RTE meat products contaminated with the pathogen continue to occur. In December 1998, Bil Mar Foods had a Class 1 recall of frankfurters and luncheon meats contaminated with *L. monocytogenes* that was associated with 37 cases of listeriosis (USDA-FSIS, 1999). Another recall associated with *L. monocytogenes* occurred in January 1999, when Thorn Apple Valley of Dixie Food Division had a Class 1 recall of

all their ready-to-eat meat and poultry products produced from July 6, 1998 to December 30, 1998 after samples tested positive for *L. monocytogenes* (USDA-FSIS, 1999). These recalls are caused from recontamination of the food product by *L. monocytogenes* after thermal processing when exposed to the environment and equipment during the peeling, slicing, and packaging process. This poses a risk to consumers because RTE meats, by definition, are often consumed without any further heating prior to consumption. In 2002, an outbreak of *L. monocytogenes* infections occurred in the northeastern United States linked to the consumptions of sliced turkey deli meat. This outbreak resulted in 46 confirmed illnesses, 7 deaths, and 3 stillbirths or miscarriages (CDC, 2002). A 2003 study determined the incidence of *L. monocytogenes* in RTE foods from retail markets in Maryland and northern California and reported a prevalence of 0.89% in sliced luncheon meats (Gombas, Chen, Clavero & Scott, 2003). Wang and Muriana (1994) found *L. monocytogenes* in exudate of 7.5 % of 19 different frankfurter brands tested. Food safety dealing with *L. monocytogenes* is still a concern as outbreaks continue to occur. In August 2008, Maple Leaf Foods in Toronto, Canada had an outbreak of *L. monocytogenes* that was linked to consumption of their deli meat products. As of October 17, 2008 this outbreak had resulted in 53 confirmed cases of listeriosis leading to 20 confirmed deaths while six deaths were still under investigation (PHAC, 2008).

To further protect people from the incidence of *L. monocytogenes* in RTE meat products, the USDA FSIS issued a final rule to prevent the adulteration of post lethality exposed RTE meats by *L. monocytogenes*. The regulation, established in 2003, set out three alternatives establishments can use in order to comply with the new regulatory requirements (USDA, 2003). These three alternatives include:

Alternative 1. Use of a post lethality treatment that reduces or eliminates microorganisms and an antimicrobial agent or process that suppresses or limits growth of *L. monocytogenes*.

Alternative 2. Use of either a post lethality treatment that reduces or eliminates microorganisms on the product or an antimicrobial agent or process that suppresses or limits growth of *L. monocytogenes*.

Alternative 3. Use of sanitation measures only

Processors who produce post-lethality exposed RTE meats must choose one of the above alternatives. Establishments opting for Alternative 1 will likely decrease the incidence of *L. monocytogenes* contamination in their products compared to Alternatives 2 or 3. Therefore, if an establishment chooses Alternative 1 the USDA FSIS will conduct fewer *L. monocytogenes* tests on their products. Irradiation has shown to be an effective way in reducing or eliminating *L. monocytogenes* in RTE meat products (Fu, Sebranek & Murano, 1995; Knight, Castillo, Maxim, Keeton & Miller, 2007a; Zhu et al., 2005a; Zhu, Mendonca, Ismail, Du, Lee & Ahn, 2005b) and therefore would make an excellent post lethality treatment to meet Alternatives 1 and 2.

Mechanism of Microbial Reduction

The primary purpose for using ionizing radiation in food is to eliminate and reduce the growth of microorganisms. When subjected to irradiation, chemical changes can occur. These chemical changes are a result of ionization which takes place because the irradiation source (gamma rays, X-rays, or accelerated electrons) ejects electrons from chemical bonds which disrupt the structure of molecules. If the molecule happens to be deoxyribonucleic acid (DNA), the result is damaging to the cell. Breaking bonds on the DNA molecule is the primary mechanism by which irradiation destroys

microorganisms, because it causes the cells to lose its ability to replicate (Murano, 1995a). More specifically, the main effect of irradiation to microorganisms is DNA base damage. This damage includes single-strand and double-strand DNA breaks as well as cross-linking between bases (Olson, 1998).

Radiation damage to DNA can occur by both direct and indirect effects. Direct effects are a result of direct interactions of ionizing radiation with DNA. When ionizing radiation is absorbed in the biological material, it will act directly on critical targets in the cell. If these targets are DNA molecules, they will become ionized or excited, resulting in damage to the DNA molecule (Diehl, 1995). This damage to the cell's DNA, if serious enough, can lead to the death of the cell and is the dominating mode of inactivation when dry spores are irradiated. In addition to direct effects causing cell inactivation, indirect effects also occur. Besides DNA, ionizing radiation interacts with other cellular components, predominately water, to produce free radicals that further damage cellular DNA. This mode of inactivation is important to vegetative cells because of the high amount of water, nearly 80%, contained in their cytoplasm. Toxic oxygen derivatives and free radicals are formed by the radiolysis of water (hydrogen peroxide (H_2O_2), hydrogen atoms ($\bullet\text{H}$), hydrated electrons (e^-_{aq}), and hydroxyl radicals ($\bullet\text{OH}$)) which interact with DNA and can cause cell death (Andrews et al., 1998; Diehl, 1995).

In addition to the three levels of radiation application, (low dose, medium dose, and high dose) the following trade names have been given to these general ranges that relate more to the function of irradiation rather than the dose (Andrews et al., 1998; Diehl, 1995; Satin, 1996).

Radurization refers to treatment of foods with ionizing radiation sufficient to increase shelf-life by reducing the initial number of spoilage organisms before or immediately after packaging. This amount varies with individual products because spoilage conditions and storage conditions change with each commodity. Radurization doses are in the low to medium dose range, <2 kGy.

Radication is the treatment of foods with ionizing radiation sufficient to reduce levels of non-spore-forming pathogens, including parasites, to an undetectable level, thus, reducing the risk of foodborne illness to near zero. This amount varies depending on the product and suspected pathogens. Typically doses are considered medium dose level and include the 3 kGy to 5 kGy range.

Radappertization refers to the treatment of foods with ionizing radiation sufficient to achieve sterility. This is the highest level of irradiation processing in which doses are generally >10 kGy. This application allows for shelf stability at ambient temperatures similar to the canning process, provided the package is not damaged. Radappertization doses are sufficient to reduce the number and/or activity of viable microorganisms to such an extent that very few, if any, are detectable by bacteriological testing methods.

Factors Affecting Radiation Sensitivity of Microorganisms

Effects of ionizing irradiation affect different organisms differently. The sensitivity of a particular organism to irradiation is dependent upon several intrinsic and extrinsic factors. It is generally accepted that the simpler the life form, the more resistant to irradiation the organism is and the higher the dose needed for inactivation. Listed in decreasing order of resistance, are organisms of different radiation sensitivities: viruses, bacterial spores, vegetative bacterial cells, yeasts, molds, and parasites (Diehl, 1995; Murano, 1995a).

Temperature is one factor that impacts the effectiveness of irradiation on a food product by influencing the indirect effects caused mainly by the radiolysis of water (Andrews et al., 1998). As temperature of the product decreases, the mobility of free radicals is hindered, thus reducing the potential to inactivate vegetative cells. When a food or meat product is frozen, the free water is tied up which limits free radical movement throughout the product. This creates a protective effect and decreased radiation sensitivity for microorganisms. Although freezing may inhibit the anti-microbial effects of free radicals produced from ionizing radiation, it also protects the products sensory quality and reduces chemical changes during irradiation processing that may be created (Andrews et al., 1998; Diehl, 1995; Murano, 1995b).

Water activity has similar effects as temperature on a microorganism's resistance to irradiation. When water activity is low in dry foods, frozen foods, or foods with high salt and sugar content, the indirect effects of radiolytic products are limited and bacterial resistance to irradiation is increased (Andrews et al., 1998). Food products with high water activity not only are more ideal for microorganism growth, but also allow free

radicals to migrate easier resulting in more interaction with cellular DNA. The easier it is for free radicals to interact with DNA, the greater the sensitivity to irradiation (Andrews et al., 1998; Diehl, 1995; Murano, 1995a; O'Bryan et al., 2008; Radomyski et al., 1994).

The composition of the food component irradiated will also affect the irradiation sensitivity of bacteria. Individual food components compete with bacteria for interaction with radiolytic products that are produced during the radiolysis of water (Andrews et al., 1998). For example, meats are high in protein and increasing amounts of protein may protect microorganisms against the damaging effects of irradiation by neutralizing free radicals (Diehl, 1995). The degree of complexity of any food matrix is unique, and the application of D-values for an irradiation process must be established for each combination of food product and bacterium of interest (Andrews et al., 1998).

Product formulation also plays a role in a bacteria's sensitivity to irradiation. Antimicrobials potassium lactate and sodium diacetate can inhibit the growth of *Listeria monocytogenes* in RTE products. Incorporation of sodium diacetate and potassium lactate into the product formulation has been shown to increase the radiation sensitivity of *L. monocytogenes* and decrease its D-value (Knight et al., 2007a; Sommers & Fan, 2003a; Sommers, Fan, Niemira & Sokorai, 2003b). Citric acid has also been shown to increase radiation sensitivity of *L. monocytogenes* when incorporated into frankfurter formulation (Sommers, Fan, Handel & Sokorai, 2003c). Not all ingredients, however, added to RTE meat formulations have an effect on bacterial radiation sensitivity. Sommers and Fan (2002) reported that the radiation resistance of *L. monocytogenes* was unaffected in beef bologna containing dextrose concentrations of 0, 2, 4, 6, or 8%. Soy protein concentrate added to beef bologna from 0 to 3.5% was also found to have no effect on the radiation

sensitivity of *L. monocytogenes* (Sommers, Fan, Niemira & Handel, 2001). Sommers and Thayer (2000) surface inoculated several different brands of commercially available frankfurters with *L. monocytogenes* and irradiated them. The D-values they found ranged from 0.49 kGy to 0.71 kGy for the different brands of frankfurters tested. The authors determined that the range in D-values were a result of the difference in product formulations of the frankfurters. They concluded that irradiation dosage should be customized to each individual product's formulation.

Another factor having an effect of the radiation sensitivity of microorganisms is the environment during radiation exposure. The most important factor affecting a product's environment during irradiation is packaging. Packaging creates the environment and determines what atmosphere the product will be in during irradiation. The presence of oxygen during irradiation will increase the radiation sensitivity to microorganisms and lower D-values. Highly reactive free radicals produced during irradiation are capable of interacting with oxygen to produce peroxides. This leads to further reactions with microorganisms leading to inactivation (Diehl, 1995). Consequently, the presence of oxygen increases irradiation-induced damage to food components resulting in negative quality changes. To negate these potential quality changes, vacuum packaging or modified atmosphere packaging (MAP) can be implemented. Knight et. al. (2007b) reported that vacuum packaged frankfurters displayed less changes in sensory characteristics due to irradiation than aerobically stored frankfurters.

Effect of Irradiation on *Listeria* in RTE meats

Irradiation has shown to be an effective way in reducing or eliminating *L. monocytogenes* in RTE meat products. The ionizing radiation dose required for a 5 log reduction in *L. monocytogenes* from frankfurters, bologna, ham, and deli turkey meat ranges from a 2.45 kGy to 3.75 kGy dose depending on product formulation (Foong, Gonzalez & Dickson, 2004; Sommers et al., 2003b; Sommers et al., 2000). Zhu et al. (2005b) reported that an irradiation dose of 1.0 kGy and 2.5 kGy resulted in a 2.0 log to 5.0 log reduction in *L. monocytogenes* depending on product formulation. Additionally, Fu et al. (1995) found that a dose of 1.8 kGy created almost a 6 log reduction of *L. monocytogenes* in cured ham. Knight et al. (2007a) showed the effectiveness of irradiation controlling *L. monocytogenes* in vacuum packaged frankfurters. In that study, frankfurters irradiated at 1.8 kGy resulted in a 3 log reduction in *L. monocytogenes* while a dose of 2.6 kGy resulted in a 5 log reduction of the pathogen. Foong et al. (2004) inoculated a five-strain *L. monocytogenes* culture onto six different types of RTE meats (frankfurters, ham, roast beef, bologna, smoked turkey with lactate, and smoked turkey without lactate). The meats were vacuum packaged and irradiated. Populations of *L. monocytogenes* were recovered by surface plating on nonselective and selective media. Using nonselective media, the authors found that a 1.5 kGy and 2.5 kGy dose resulted in a 3-log and 5-log reduction in *L. monocytogenes* respectively. Similar results were found when plating with selective media for the bologna, roast beef, and both types of turkey. However, in the frankfurters and ham, a 2.0 kGy and 3.0 kGy dose were required to achieve a 3-log and 5-log reduction in *L. monocytogenes* respectively when selective

media was used. Cabeza et al. (2007) reported a 2.5 kGy dose of irradiation will completely eliminate *L. monocytogenes* in RTE cooked ham.

Although irradiation is effective in controlling *L. monocytogenes*, current food safety practices cannot be ignored. In a study by Fu and others (1995), cured ham that was previously irradiated at 1.8 kGy eliminated *L. monocytogenes* to undetectable levels; however, after 7 days of storage the product was temperature abused at 25°C resulting in a rapid growth of *Listeria* to 6 log CFU/g by day 9. Sommers et al. (2003b) reported that bologna irradiated at 1.5 kGy and stored at 9°C allowed *L. monocytogenes* to quickly recover post-irradiation treatment and reach a density of 6 to 8 log CFU/g after 8 weeks of storage. Although irradiation is effective in controlling the post lethality contamination of *L. monocytogenes* in RTE meats, it does not replace prior food safety and proper food handling procedures. Temperature abuse and product mishandling can still create an unsafe product. Irradiation in combination with prior safe handling procedures and food safety processes such as Hazard Analysis of Critical Control Points (HACCP) and Standard Sanitation Operating Procedure (SSOP) programs could be used to yield a microbiological safe product.

Quality Changes in Processed Meats by Irradiation

There has been less interest in applying irradiation to processed meat and poultry products compared with fresh meat and poultry. This is mainly because improved safety and shelf-life extension can be extended by more consumer friendly preservation methods such as curing, heat pasteurization, fermentation, addition of antimicrobials, and more recently high-pressure pasteurization. However, the risk of *L. monocytogenes*

recontamination of these processed meats during slicing, peeling, and packaging has renewed interest in irradiation to eliminate this pathogen. Ionizing radiation can effectively eliminate or reduce *L. monocytogenes* in processed meats, but may also affect their quality factors, including color, lipid oxidation, odor, and flavor.

Color Changes due to Irradiation

Sodium nitrite is responsible for the cured pink color consumers associate with processed meats such as frankfurters and cured ham. Irradiation effects on these products' characteristic color have been studied. Terrell et al. (1981a) studied the effect of irradiation (0-32 kGy) on color characteristics of frankfurters formulated with various amounts of sodium nitrite (0-100 mg/kg). It was reported that frankfurters cured with the highest amount of nitrite (100 mg/kg) had more desirable external, internal, and cured color sensory results regardless of irradiation dose. Another study conducted by Terrell et al. (1982) determined that irradiation had no significant difference in internal color values in pork/beef and chicken/turkey frankfurters when irradiated at 0, 8, and 32 kGy.

Shahidi et al. (1991) irradiated cooked pork homogenate formulated with and without nitrite at 5 and 10 kGy. The a^* (redness) values, for all samples, regardless of treatment, decreased over the 3 week storage period. Irradiation had no detrimental effects on the color of any cured meat samples. Houser et al. (2003) showed similar results in cured ham. The authors irradiated ham at 4.5 kGy at different points in the curing process (before injection, after injection, and after cooking) and reported no significant difference in a^* values. They concluded that irradiation had no impact on cured meat color regardless of when irradiation was applied during the manufacturing

process. Houser et al. (2005a) also irradiated sliced cured ham in vacuum and aerobic packaging at 0, 1.2, 2.3, and 4.5 kGy and stored for 0 and 7 days. Irradiation decreased cured color as the dose increased from 0 to 4.5 kGy as evidenced by lower a^*/b^* ratios regardless of packaging atmosphere. However, cured color was regenerated over time and resulted in higher a^*/b^* ratios on day 7 compared with day 0 for the 4.5 kGy treatment. Sliced ham and all pork frankfurters irradiated at 1.6 kGy also showed no change in color due to irradiation throughout an 8 week storage period (Houser et al., 2005b). Knight et al. (2007b) irradiated frankfurters (0, 1.8, or 2.6 kGy) formulated with 0% or 3% potassium lactate/sodium diacetate solution and stored them aerobically or vacuum packaged at 4 °C for 4 or 8 weeks. The authors found that irradiation had no effect on cured color. These results agree with that of previously mentioned studies in that irradiation of processed meat products containing nitrite has little effect on cured meat color.

Lipid Oxidation production of Irradiated Processed Meats

Oxidation is the process of removing electrons from a molecule resulting in a more positively charged molecule. In meat systems it can be defined as the transfer of electrons, hydrogen abstraction or flow of unpaired electrons (McMillin, 1996). Meat is particularly susceptible to oxidation since it contains a high concentration of lipids, prooxidants, and in some cases oxygen (Decker & Mei, 1996). Lipids become rancid as a result of oxidation, and oxidative rancidity is one of the main factors limiting the quality and acceptability of meat products (Gray, 1978; Morrissey, Sheehy, Galvin, Kerry & Buckley, 1998). Acceptability of a meat product depends on the extent to which oxidative

rancidity occurs (Gray, 1978). Factors that can affect oxidation in meat systems include heat, exposure to light, metal ions, storage time, freezing, salts, pH, enzyme activity, and exposure to air or oxygen (McMillin, 1996). In meats, lipid oxidation occurs more readily in unsaturated fatty acids. The susceptibility of oxidation of fatty acids increases in relation to their degree of unsaturation (Gray, 1978). Oxidation is caused from a free radical chain reaction that starts when a hydrogen atom is eliminated from an unsaturated fatty acid by bonding with oxygen (O_2) or other catalysts resulting in a fatty acyl radical (Morrissey et al., 1998). The formation of these reactive free radicals initiates chain reactions such as lipid peroxidation (McMillin, 1996). In processed meats, factors that influence the rate of lipid peroxidation are composition of raw materials, animal species, time post-mortem, heating, comminution, and added ingredients such as salt, spices and antioxidants (McMillian, 1996). Although cured meat products are exposed to conditions that promote lipid oxidation, added ingredients such as phosphates, sodium nitrite, and natural and synthetic antioxidants inhibit lipid oxidation.

Lipid oxidation in meat systems is commonly measured using the 2-thiobarbituric acid test (TBA) developed by Tarladgis et al. (1960) or slightly modified versions of this method. This method measures the mg of malonaldehyde per 1000 g of product in the sample test. Malonaldehyde is a dicarbonyl product resulting from the oxidation of unsaturated fatty acids. TBA values and rancidity scores by sensory panel were found to be highly correlated. Also, a threshold range of 0.5 to 1.0 has been reported for detection of off-odor in fresh ground pork ham (Tarladgis et al., 1960). Because malonaldehyde reacts with other compounds besides 2-thiobarbituric acid, it is more appropriate to refer to TBA values as TBA reactive substances (TBARS) (Decker, Chan & Faustman, 1998).

The effect irradiation has on lipid oxidation in processed meats has not been extensively researched but may vary with the different ingredients used in different products. Sodium nitrite and phosphates for example are antioxidants while salt has the opposite effect and promotes lipid oxidation. Shahidi et al. (1991) has shown that nitrite addition to meat prevents lipid oxidation. They reported lower TBA values during storage for cooked, cured pork homogenate treated with irradiation at 0, 5, and 10 kGy compared with uncured irradiated pork homogenate in the presence of sodium ascorbate. This agrees with Fu et al. (1995) in which irradiated cured ham slices at 0.9, and 1.8 kGy showed no significant effects of TBA values throughout 9 days of storage compared to non-irradiated controls. Zhu et al. (2003) irradiated RTE turkey ham at 0, 1, or 2 kGy and stored for 14 days at 4°C. They reported significantly higher TBA values ($P<.05$) for turkey ham irradiated at 1 and 2 kGy at day 0, but the difference disappeared after 7 and 14 days storage. The authors concluded that the small change in oxidation at day 0 was the result of free radicals produced during the irradiation process but did not increase throughout storage because of the exclusion of oxygen in the vacuum package. This hypothesis is supported by Houser et al. (2003) who irradiated cured ham at different stages in the manufacturing process with a 4.5 kGy dose. The authors reported that irradiation only slightly increased TBA values for cured ham and did not change throughout 90 days storage. All TBA values were very low and well below the suggested threshold of 0.5 to 1.0 for oxidative rancidity as reported by Tarladgis et al.(1960). This agrees with another study of Houser et al. (2005b) in which the authors reported that irradiation of 1.6 kGy had no significant effect on the TBA values of cured ham and frankfurters throughout 8 weeks of storage. These studies suggest that low to medium

dose irradiation has a limited effect on the lipid oxidation of cured meats. However, if higher irradiation doses were used the results may have been different. Terrell et al. (1981a) reported a dose dependent increase in TBA values for irradiated (0, 8, 32 kGy) pork/beef frankfurters.

Off-Odor Production of Irradiated Processed Meats

In addition to lipid oxidation and color, odor is another important factor that influences consumers' acceptability of meat products. A 21 member sensory panel found cooked corn beef irradiated at 25 kGy to increase off-odor when compared to a non-irradiated control at week 1 and week 4 of storage (Shults, Cohen, Howker & Wierbicki, 1977). Both studies done by Terrell et al. (1981a; 1981b) determined that increased levels of irradiation (0, 8, and 32 kGy) caused increased off-odor production. The authors concluded that irradiation at 8 kGy would achieve the desired effects, while not significantly decreasing the sensory quality of frankfurters. This is in agreement with Fu et al. (1995) who reported no increase in off-odor production when irradiating cured ham slices at 0 and 1.8 kGy in an anaerobic environment. Houser et al. (2003) investigated off-odor production in cured ham irradiated (4.5 kGy) at different times throughout the manufacturing process. They reported that hams irradiated after cooking had increased off-odor scores at day 0 compared to the non-irradiated control. Another study by Houser et al (2005b) demonstrated that the reason for off-odor production in irradiated processed meats is not well understood. The authors irradiated ham and frankfurters at 1.6 kGy and monitored off-odor production throughout 90 days storage. Off-odor scores were significantly ($P < 0.05$) higher for the irradiated ham treatments compared with non-

irradiated controls regardless of length of storage. In the frankfurters however, off-odor scores were not significantly ($P > 0.05$) different throughout storage for irradiated samples compared to non-irradiated controls. The results of these studies suggest that irradiation at medium to high doses causes detrimental off-odor production in meats. Irradiation of processed meats at the low dose level needs to be investigated further.

Off-flavor Production of Irradiated Processed Meats

Terrell et al. (1981a; 1981b; 1982) concluded that irradiation (0, 8, and 32 kGy) increased off-flavor development in pork/beef frankfurters in a dose dependent fashion. This is in contrast to Terrell et al. (1982) who reported that irradiation at 0 and 8 kGy for chicken and turkey frankfurters had no significant effect on off-flavor scores compared to non-irradiated controls. This agrees with Zhu et al. (2003) who irradiated turkey ham at 0, 1, and 2 kGy and reported no difference in metallic, oxidation, sulfury or sweet flavors as a result of irradiation.

The mixed results of these previous studies agree with Houser et al. (2005b) who irradiated vacuum packaged commercially produced ham and pork frankfurters at 1.6 kGy. A trained sensory panel produced off-flavor scores that were significantly higher in the frankfurters when compared to non-irradiated controls. However, these same panelists produced off-flavor scores that were not significantly different in the cured ham resulting from irradiation treatment.

Summary

Although irradiation processing is not currently approved by the FDA for RTE foods, it has been proven to be an effective method for controlling *Listeria monocytogenes* in RTE meats. If allowed, irradiation could provide another option to meet the USDA “zero tolerance” policy in post-lethality exposed RTE meats. Although irradiation could be a useful tool in improving food safety, questions still arise on the quality changes associated with irradiated meats such as off-flavors and off-odors. These detrimental effects from irradiation are not consistent across all studies and suggest other factors may be involved in the development of these quality changes. One such factor may be the difference in the physical shape of a product. An interesting recent observation (Olson, 2007) has been that identical all-beef emulsion formulations, placed in two different physical shapes, resulted in different quality effects. Specifically, it has been claimed that an all-beef frankfurter formulation resulted in minimal quality change when irradiated, but the identical all-beef formulation in sliced bologna form resulted in significant undesirable odor changes. Therefore, the objective of this research was to determine the effect of physical shape on quality characteristics of irradiated frankfurters and bologna as well as the effects of irradiation on these products’ quality attributes.

References

Andrews, L. S., Ahmedna, M., Grodner, R. M., Liuzzo, J. A., Murano, P. S., Murano, E. A., Rao, R. M., Shane, S., & Wilson, P. W. (1998). Food preservation using ionizing radiation. *Reviews of Environmental Contamination and Toxicology*, 154, 1-53.

Cabeza, M. C., Cambero, I., de la Hoz, L., & Ordonez, J. A. (2007). Optimization of E-beam irradiation treatment to eliminate *Listeria monocytogenes* from ready-to-eat (RTE) cooked ham. *Innovative Food Science & Emerging Technologies*, 8, 299-305.

Centers for Disease Control. (2002). Public Health Dispatch: outbreak of listeriosis-northeastern United States. *Morbidity and Mortality Weekly Report*, 51, 950-951,

Centers for Disease Control (March 27, 2008). "Listeriosis." Retrieved September 4, 2008, from http://www.cdc.gov/nczved/dfbmd/disease_listing/listeriosis_gi.html.

Decker, E. A., Chan, K. M., & Faustman, C. (1998). TBA as an index of oxidative rancidity in muscle foods. In 51st Annual Reciprocal Meat Conference: 1998, Storrs, CT: American Meat Science Association. P 66.

Decker, E. A., & Mei, L. (1996). Antioxidant mechanisms and applications in muscle foods. In: 49th Annual Reciprocal Meat Conference: 1996 Chicago, IL: American Meat Science Association. P 64-72.

Diehl, J. F. (1995). *Safety of Irradiated Foods*, 2nd ed. Marcel Dekker, Inc. New York

Food and Drug Administration (September 3, 2008). "Foods Permitted to be Irradiated Under FDA's Regulations (21 CFR 179.26)." Retrieved September 9, 2008, from www.cfsan.fda.gov/~dms/irrafood.html.

Foong, S. C. C., Gonzalez, G. L., & Dickson, J. S. (2004). Reduction and survival of *Listeria monocytogenes* in ready-to-eat meats after irradiation. *Journal of Food Protection*, 67, 77-82.

Fox, J. A., Hayes, D. J., & Shogren, J. F. (2002). Consumer preferences for food irradiation: How favorable and unfavorable descriptions affect preferences for irradiated pork in experimental auctions. *Journal of Risk and Uncertainty*, 24, 75-95.

Fu, A. H., Sebranek, J. G., & Murano, E. A. (1995). Survival of *Listeria monocytogenes* and *Salmonella typhimurium* and quality attributes of cooked pork chops and cured ham after irradiation. *Journal of Food Science*, 60, 1001-1005.

Gombas, D. E., Chen, Y. H., Clavero, R. S., & Scott, V. N. (2003). Survey of *Listeria monocytogenes* in ready-to-eat foods. *Journal of Food Protection*, 66, 559-569.

Goresline, H. E. (1982). Historical aspects of the radiation preservation of food. . In E. S. Josephson, and M.S. Peterson (Ed.), *Preservation of Food by Ionizing Radiation*. (1-46). Boca Raton, FL: CRC Press Inc.

Gray, J. I. (1978). Measurement of lipid oxidation - Review. *Journal of the American Oil Chemists Society*, 55, 539-546.

Houser, T. A., Sebranek, J. G., & Lonergan, S. M. (2003). Effects of irradiation on properties of cured ham. *Journal of Food Science*, 68, 2362-2365.

Houser, T. A., Sebranek, J. G., Maisonet, W. N., Cordray, J. C., Ahn, D. U., & Dixon, P. M. (2005a). Irradiation-induced cured ham color fading and regeneration. *Journal of Food Science*, 70, C281-C285.

Houser, T. A., Sebranek, J. G., Maisonet, W. N., Cordray, J. C., Wiegand, B. R., Ahn, D. U., & Lee, E. J. (2005b). The effects of irradiation at 1.6 kGy on quality characteristics of commercially produced ham and pork frankfurters over extended storage. *Journal of Food Science*, 70, S262-S266.

Johnson, A. M., Reynolds, A. E., Chen, J. R., & Resurreccion, A. V. A. (2004). Consumer acceptance of electron-beam irradiated ready-to-eat poultry meats. *Journal of Food Processing and Preservation*, 28, 302-319.

Knight, T. D., Castillo, A., Maxim, J., Keeton, J. T., & Miller, R. K. (2007a). Effectiveness of potassium lactate and sodium diacetate in combination with irradiation to control *Listeria monocytogenes* on frankfurters. *Journal of Food Science*, 72, M26-M30.

Knight, T. D., Miller, R., Maxim, J., & Keeton, J. T. (2007b). Sensory and physiochemical characteristics of frankfurters formulated with potassium lactate and sodium diacetate before and after irradiation. *Journal of Food Science*, 72, S112-S118.

McMillin, K. W. (1996). Initiation of oxidative processes in muscle foods. In: 49th Annual Reciprocal Meat Conference: 1996 Chicago, IL: American Meat Science Association. P 52-53.

Mead, P. S., Slutsker, L., Dietz, V., McCaig, L. F., Bresee, J. S., Shapiro, C., Griffin, P. M., & Tauxe, R. V. (1999). Food-related illness and death in the United States. *Emerging Infectious Diseases*, 5, 607-625.

Morrissey, P. A., Sheehy, P. J. A., Galvin, K., Kerry, J. P., & Buckley, D. J. (1998). Lipid stability in meat and meat products. *Meat Science*, 49, S73-S86.

Murano, E. A. (1995a). Food Irradiation: A Sourcebook. (Ed.), *Microbiology of Irradiated Foods*. (29-61). Ames, IA: Iowa State University Press

Murano, P. S. (1995b). Food Irradiation: A Sourcebook. In E. A. Murano (Ed.), *Quality of Irradiated Foods*. (63-87). Ames, IA: Iowa State University

Nayga, R. M., Aiew, W., & Nichols, J. P. (2005). Information effects on consumers' willingness to purchase irradiated food products. *Review of Agricultural Economics*, 27, 37-48.

O'Bryan, C. A., Crandall, P. G., Ricke, S. C., & Olson, D. G. (2008). Impact of irradiation on the safety and quality of poultry and meat products: A review. *Critical Reviews in Food Science and Nutrition*, 48, 442-457.

Olson, D. G. (1995). Irradiation Processing. In E. A. Murano (Ed.), *Food Irradiation: A Sourcebook*. (3-28). Ames, IA: Iowa State University Press

Olson, D. G. (1998). Irradiation of food. *Food Technology*, 52, 56-62.

Olson, D. G. (2007). Oral Communication

Public Health Agency of Canada (October 17, 2008). "*Listeria monocytogenes* Outbreak." Retrieved October 22, 2008, from www.phac-aspc.gc.ca/alert-alerte/listeria/listeria_2008-eng.php.

Radomyski, T., Murano, E. A., Olson, D. G., & Murano, P. S. (1994). Elimination of pathogens of significance in food by low-dose Irradiation - Review. *Journal of Food Protection*, 57, 73-86.

Resurreccion, A. V. A., Galvez, F. C. F., Fletcher, S. M., & Misra, S. K. (1995). Consumer attitudes toward irradiated food - results of a new study. *Journal of Food Protection*, 58, 193-196.

Satin, M. (1996). Food Irradiation; A Guidebook, 2nd ed., Techomic Publishing Co. Inc. Lancaster, PA

Schwartz, B. (1921). Effects of x-rays on Trichinae. *Jouranl of Agricultural Research*, 20, 845-854.

Shahidi, F., Pegg, R. B., & Shamsuzzaman, K. (1991). Color and oxidative stability of nitrite-free cured meat after gamma-irradiation. *Journal of Food Science*, 56, 1450-1452.

Shults, G. W., Cohen, J. S., Howker, J. J., & Wierbicki, E. (1977). Effects of sodium-nitrate and sodium-nitrite additions and irradiation processing variables on color and acceptability of corned beef briskets. *Journal of Food Science*, 42, 1506-1509.

Sommers, C., & Fan, X. (2003a). Gamma irradiation of fine-emulsion sausage containing sodium diacetate. *Journal of Food Protection*, 66, 819-824.

Sommers, C., Fan, X. T., Niemira, B. A., & Sokorai, K. (2003b). Radiation (gamma) resistance and postirradiation growth of *Listeria monocytogenes* suspended in beef bologna containing sodium diacetate and potassium lactate. *Journal of Food Protection*, 66, 2051-2056.

Sommers, C. H., & Fan, X. (2002). Antioxidant power, lipid oxidation, color, and viability of *Listeria monocytogenes* in beef bologna treated with gamma radiation and containing various levels of glucose. *Journal of Food Protection*, 65, 1750-5.

Sommers, C. H., Fan, X., Niemira, B. A., & Handel, A. P. (2001). Effect of ionizing radiation on beef bologna containing soy protein concentrate. *Journal of Food Safety*, 21, 151-165.

Sommers, C. H., Fan, X. T., Handel, A. P., & Sokorai, K. B. (2003c). Effect of citric acid on the radiation resistance of *Listeria monocytogenes* and frankfurter quality factors. *Meat Science*, 63, 407-415.

Sommers, C. H., & Thayer, D. W. (2000). Survival of surface-inoculated *Listeria monocytogenes* on commercially available frankfurters following gamma irradiation. *Journal of Food Safety*, 20, 127-137.

Tarladgis, B. G., Watts, B. M., Younathan, M. T., & Dugan, L. (1960). A distillation method for the quantitative determination of malonaldehyde in rancid foods. *Journal of the American Oil Chemists Society*, 37, 44-48.

Terrell, R. N., Heiligman, F., Smith, G. C., Wierbicki, E., & Carpenter, Z. L. (1981a). Effects of sodium-nitrite, sodium-nitrate and DL, alpha-tocopherol on properties of irradiated frankfurters. *Journal of Food Protection*, 44, 414-&.

Terrell, R. N., Smith, G. C., Heiligman, F., Wierbicki, E., & Carpenter, Z. L. (1981b). Cooked product temperature and curing ingredients affect properties of irradiated frankfurters. *Journal of Food Protection*, 44, 215-219.

Terrell, R. N., Swasdee, R. L., Smith, G. C., Heiligman, F., Wierbicki, E., & Carpenter, Z. L. (1982). Effects of sodium-nitrite, sodium acid pyrophosphate and meat formulation on properties of irradiated frankfurters. *Journal of Food Protection*, 45, 689-694.

United States Department of Agriculture Food Safety and Inspection Service (January 22, 1999). "Recall Notification Report 005-99." Retrieved October 22, 2008, from www.fsis.usda.gov/OA/recalls/rnrfiles/rnr005-99.htm.

United States Department of Agriculture Food Safety and Inspection Service (August 17, 1999). "Recall Notification Report 044-98." Retrieved October 22, 2008, from www.fsis.usda.gov/OA/recalls/rnrfiles/rnr044-98.htm.

United States Department of Agriculture (2003). Verification procedures for the *Listeria monocytogenes* regulation and microbial sampling of ready-to-eat (RTE) products for the FSIS verification testing program. FSIS Directive 10,240.4

Wang, C. H., & Muriana, P. M. (1994). Incidence of *Listeria monocytogenes* in packages of retail franks. *Journal of Food Protection*, 57, 382-386.

World Health Organization (1981). Wholesomeness of irradiated food: report of a Joint FAO/IAEA/WHO Expert Committee. World Health Organization. Geneva, Switzerland

World Health Organization (1999). High-Dose Irradiation: Wholesomeness of Food Irradiated with Doses Above 10 kGy: Report of a Joint FAO/IAEA/WHO Study Group. World Health Organization. Geneva, Switzerland

Zhu, M. J., Du, M., Cordray, J., & Ahn, D. U. (2005a). Control of *Listeria monocytogenes* contamination in ready-to-eat meat products. *Comprehensive Reviews in Food Science and Food Safety*, 4, 34-42.

Zhu, M. J., Lee, E. J., Mendonca, A., & Ahn, D. U. (2003). Effect of irradiation on the quality of turkey ham during storage. *Meat Science*, 66, 63-68.

Zhu, M. J., Mendonca, A., Ismail, H. A., Du, M., Lee, E. J., & Ahn, D. U. (2005b). Impact of antimicrobial ingredients and irradiation on the survival of *Listeria monocytogenes* and the quality of ready-to-eat turkey ham. *Poultry Science*, 84, 613-620.

CHAPTER 3. EFFECTS OF GEOMETRIC SHAPE AND SERVING TEMPERATURE ON QUALITY CHARACTERISTICS OF IRRADIATED BOLOGNA AND FRANKFURTERS

A paper to be submitted to the Journal of Meat Science

A. L. Krause, D. G. Olson, J. G. Sebranek, A. Mendonca

Abstract

The effects of irradiation (1.1 kGy, and 2.2 kGy) on bologna and frankfurters were measured to determine if variations in geometric size create differences in quality of irradiated ready-to-eat meats. The characteristics measured included oxidation (TBARS values), color (CIE L*, a*, b*), pH, texture, proximate analysis and sensory attributes. Sensory was completed on bologna and frankfurters served cold and then again hot. Irradiation up to 2.2 kGy had no effect on color, TBARS values, or texture of vacuum packaged bologna and frankfurters. Irradiation significantly ($P < 0.05$) lowered aroma and flavor scores while increasing off-aroma and off-flavor scores in product served cold, but was not significant when the product was served hot. Geometric size did not create differences in quality of irradiated bologna and frankfurters but serving temperature did.

Introduction

Despite recent advances in food technology, food safety continues to be a concern for the food industry. It is estimated that foodborne diseases account for 76 million illnesses, 325,000 hospitalizations and 5000 deaths in the United States each year (Mead et al., 1999). Of these illnesses, the Centers for Disease Control (CDC) (2008) estimates 2500 cases of listeriosis occur in the United States each year resulting in 500 deaths.

Listeria monocytogenes, the organism responsible for listeriosis, is a significant threat to ready-to-eat (RTE) meat products because of its ubiquitous nature, resistance to salt, and its ability to grow at refrigerated temperatures (Zhu, Du, Cordray & Ahn, 2005a). Since 1989, the United States Department of Agriculture (USDA) has had a “zero tolerance” policy in effect with regard to *L. monocytogenes* in RTE meat products. Any product testing positive for *L. monocytogenes* is classified as adulterated (USDA, 2003).

Thermal processing effectively controls and kills *L. monocytogenes*, however, food recalls of RTE meat products contaminated with the pathogen continue to occur. These recalls are caused from recontamination of the food product by *L. monocytogenes* after thermal processing when exposed to the environment and equipment during the peeling, slicing, and packaging process (Gombas, Chen, Clavero & Scott, 2003; Wang & Muriana, 1994). Since RTE meats are often consumed without reheating prior to consumption, consumers could be at risk. Consumer safety calls for processes that can ensure that RTE meat products are free of *L. monocytogenes* after packaging has been completed.

One procedure that can be used to eliminate *L. monocytogenes* after packaging is irradiation. Although irradiation processing is not currently approved by the FDA for RTE meat products, it has been proven to be an effective method for controlling *L. monocytogenes* in RTE meats (Foong, Gonzalez & Dickson, 2004; Sommers, Fan, Niemira & Sokorai, 2003b; Sommers & Thayer, 2000). In a study by Fu et al. (1995), cured ham irradiated at 1.8 kGy eliminated *L. monocytogenes* to undetectable levels. Since RTE meats would be irradiated after packaging, there would not be an opportunity for contamination until the consumer opened the package. If approved, irradiation could

provide another option to meet the USDA “zero tolerance” policy in post-lethality exposed RTE meats.

Although irradiation could be a useful tool in improving food safety, questions still arise on the quality changes associated with irradiated meats such as off-flavors and off-odors (Terrell, Heiligman, Smith, Wierbicki & Carpenter, 1981a; Terrell, Smith, Heiligman, Wierbicki & Carpenter, 1981b; Terrell, Swasdee, Smith, Heiligman, Wierbicki & Carpenter, 1982). This is in contrast to Zhu et al. (2003) who irradiated turkey ham at 0, 1, and 2 kGy and reported no difference in off-flavors as a result of irradiation. The mixed results of these quality changes were also found in cured ham and pork frankfurters (Houser et al., 2005b).

These detrimental effects from irradiation are not consistent across all studies suggesting other factors may be involved in the development of off-odors and off-flavors in RTE meat products. One such factor may be the difference in the physical shape of a product. Since RTE products often exist in a variety of shapes and sizes, the potential for quality differences may exist in the product after irradiation. Therefore, the objective of this research was to determine the effect of physical shape and size on quality characteristics of common RTE meats following irradiation.

Materials and Methods

Raw Materials

Beef trim (90/10) and pork trim (50/50) were obtained from the Iowa State University Meat Laboratory (Ames, IA, U.S.A.). The beef and pork trim were ground (Biro grinder, Model 7552, Marblehead, OH, U.S.A.) through a ½ inch (1.27 cm) plate

and blended in appropriate rations to reach a beginning fat content of 28% for the meat block. The fat content of both the beef and pork trim was determined using an Anyl Ray Fat Analyzer (Kartridg Pak, Model 316-4A, Davenport, IA, U.S.A.). For each replication, one 60 kg batch of base emulsion (Table 1) was produced with half of it going for use in frankfurter production while the other half of the emulsion was used for bologna production.

Table 1. Ingredients used to produce basic emulsion.

Ingredients	%
Beef (90/10)	53.84
Pork (50/50)	19.92
Ice/Water	22.12
Seasoning ^a	2.46
Salt	1.48
Curing Salt ^b	0.18

^aIowa State University Frankfurter Seasoning (Blend No. EJ-93-150-001, A.C. Legg Inc.)

^b(6.25% sodium nitrite)

Bologna and Frankfurter Preparation

Emulsions were prepared in a bowl chopper (Kramer-Grebe bowl chopper, model VSM65) and were chopped under vacuum. The beef, salt, curing salt, and half of the ice water was added and chopped until the product temperature reached 5°C. Next, the pork trim, seasonings, and the other half of the ice water were added and chopped under vacuum until the product temperature reached 13°C. The emulsion was then split in two 30 kg batches.

Frankfurters were stuffed into 24mm cellulose frankfurter casings (ViscoFan USA, Inc.) using a vacuum stuffer (Frey Konti-S200; Herbrechtigen, Germany) and hung

on smokehouse trucks for thermal processing. Thermal processing and smoking (natural smoke) was done using an Alkar thermal processing unit (Model MT EVD RSE 4, Alkar Engineering Corp., Lodi WI, U.S.A.). The final internal temperature of the product was brought to 74°C using the cooking schedule in Table 2.

Table 2. Cooking Schedule for Frankfurters

Step Type	Step Time	Dry bulb (°C)	Wet bulb (°C)	RH (%)	IT* (°C)
Cook	00:30	63	0	0	---
Smoke Cook	00:30	68	0	0	---
Cook	00:15	68	0	0	---
Cook	00:10	82	60	36	---
Steam Cook	00:01	82	82	100	74
Cold Shower	00:15	10	10	0	---

*IT = Internal Temperature

The product was then moved to the cooler and held overnight at a temperature of 0°C prior to peeling. A Townsend peeler (model 2600, Townsend Engineering) was used to peel the frankfurters prior to packaging. Eight frankfurters were packaged in a single layer in vacuum bags (B-2470, Cryovac Sealed Air Corp., Duncan, SC, U.S.A.) using a Multivac double chamber-packaging machine (model AG800). The frankfurter packages were randomly assigned to the three irradiation treatment groups (0, 1.1, and 2.2 kGy), placed in cardboard boxes, returned to the cooler (0°C), and held there throughout the remainder of the study until products were analyzed.

Bologna was stuffed into a No. 6 (106.17 mm) fibrous casing (ViscoFan USA, Inc.) using a vacuum stuffer (Frey Konti-S200; Herbrechtigen, Germany) and hung on smokehouse trucks for thermal processing. Thermal processing and smoking (natural smoke) was done using an Alkar thermal processing unit (Model MT EVD RSE 4, Alkar

Engineering Corp., Lodi WI, U.S.A.). The final internal temperature of the product was brought to 74°C using the cooking schedule in Table 3.

Table 3. Cooking Schedule for Bologna.

Step Type	Step Time	Dry bulb (°C)	Wet bulb (°C)	RH (%)	IT* (°C)
Cook	01:00	38	32	65	---
Cook	00:43	54	40	42	---
Cook	00:45	66	46	34	---
Smoke Cook	01:00	80	66	52	---
Cook	00:01	89	70	64	60
Cook	00:01	85	80	81	74
Cold Shower	00:30	10	10	0	---

*IT = Internal Temperature

The product was then moved to the cooler and held overnight at a temperature of 0°C. The bologna was sliced (Bizerba Slicer, Model A500, Balingen, Germany) prior to packaging. Six slices of bologna equaling the same thickness as a frankfurter, so that both products would have the same dose depth profile during irradiation, were stacked and packaged in vacuum bags (B-2470, Cryovac Sealed Air Corp., Duncan, SC, U.S.A.) using a Multivac double chamber-packaging machine (model AG800). The bologna packages were randomly assigned to the three irradiation treatment groups (0, 1.1, and 2.2 kGy), placed in cardboard boxes, returned to the cooler (0°C), and held there throughout the remainder of the study until the products were analyzed.

The above procedures were replicated 3 times. Physical, chemical, and sensory analyses were completed on the products (frankfurters and bologna) at days 20-26 storage. The resulting six treatments were as follows:

- Frankfurters, No irradiation (0 kGy) (control)
- Frankfurters, Irradiation (1.1 kGy)

- Frankfurters, Irradiation (2.2 kGy)
- Bologna, No irradiation (0 kGy) (control)
- Bologna, Irradiation (1.1 kGy)
- Bologna, Irradiation (2.2 kGy)

Irradiation

Irradiation was conducted at the Iowa State University Linear Accelerator Facility (LAF). Product was held for 6 days after packaging and transferred from the cooler to the LAF immediately before irradiation. Product was exposed to ambient temperatures for approximately 45 minutes during irradiation. For consistency purposes, control samples were also exposed to this ambient temperature for the same time. Product was placed in single layers in an open cardboard box on stainless steel transfer carts for irradiation. Product was irradiated using a CIRCE IIR electron beam irradiator (Thompson-CSF Linac, France). Each replication was processed separately through the LAF while the different products (frankfurters and bologna) in each replication were processed together. Products were irradiated at an energy level of 10 MeV with an approximate dose rate of 74 kGy/minute to achieve a target dose of 1.1 kGy and 2.2 kGy in the final product. Due to the thickness of the products, only a single sided irradiation pass was necessary. Absorbed doses were read from alanine dosimeters that were placed on the top and bottom of one sample per transfer cart. The dosimeters were then read using a 104 Electron Paramagnetic Resonance instrument (Brinker Instruments, Inc., Billerica, MA, U.S.A.) to determine the actual absorbed dose. After irradiation, products were immediately returned to the boxes and stored at 0°C for the duration of the study.

pH Analysis

Frankfurter and bologna samples were measured for pH using a pH/ion meter (Accumet 925, Fisher Scientific, Fair Lawn, NJ, U.S.A.) equipped with an electrode (Accument Flat Surface Epoxy Body Ag/AgCl combination Electrode Model 13-620-289, Fisher Scientific, Fair Lawn, NJ, U.S.A.) calibrated with phosphate buffers 4.0 and 7.0. Frankfurters were removed from package and sliced in half. The pH electrode was then inserted into the middle of the frankfurter and measured for pH. Bologna slices approximately 20 mm thick were removed from package and the pH electrode was inserted into the middle of the bologna slice to measure the pH. The electrode was cleaned with deionized water between measurements. For each treatment, measurements were made in duplicate.

Fat, Moisture, and Protein Analysis

Proximate composition was determined for the frankfurter and bologna samples including crude fat (AOAC, 1990a), moisture (AOAC, 1990b), and crude protein (AOAC, 1993).

Lipid Oxidation

Lipid oxidation was measured twice for each treatment. Once when the product was immediately removed from storage at 0°C and once when the product was reheated to 71°C prior to measurement. Lipid oxidation was then measured by the modified 2-thiobarbituric acid reactive substances (TBA) test as described for cured meats (Zipser &

Watts, 1962). TBARS values were reported as mg of malonaldehyde equivalents/kg of meat sample. For each treatment, measurements were made in duplicate.

Color Analysis

Color measurements were conducted using a Hunterlab Labscan spectrophotometer (Hunter Associated Laboratories Inc., Reston, VA, U.S.A.) The Hunterlab Labscan was standardized by placing Saran over the white standard tile. Values for the white standard tile were $X=80.45$, $Y=85.37$, and $Z=90.79$. Interior color of the frankfurters was measured immediately after removing samples from their package and cutting the frankfurters in half perpendicular to their length. All samples were covered with Saran and measurements were read through the film. One measurement was made per frankfurter with a total of 3 frankfurters measured per treatment. The average of the 3 measurements was used for data analysis. Bologna color measurements were measured immediately after removing from packaging. After removal from package, the top slice of bologna was discarded and color measurements were taken on the resulting bologna slices after covering with Saran. Three measurements were made on the internal area of 3 separate bologna slices for a total of 3 measurements per treatment. The average of the 3 measurements was used for data analysis.

Commission International d'éclairage (CIE) L^* (lightness), a^* (redness), and b^* (yellowness) were determined for both frankfurters and bologna. Illuminant A, 10° standard observer with a 0.64 cm viewing area and 1.02 cm port size, was used to measure the internal color of frankfurter samples. Illuminant A, 10° standard observer

with a 4.44 cm viewing area and 5.08 cm port size, was used to measure the internal color of bologna.

Texture

Texture analysis was performed to determine the internal firmness of both frankfurters and bologna using a TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). The tests were conducted using a 3mm diameter stainless steel puncture probe (Model TA-52). The 3mm probe was programmed to penetrate 12 mm into each frankfurter or bologna slice after the sample's surface was detected at 12 grams resistance. The penetration speed was 1.5mm/second with a pre-test speed of 3.0mm/second and a post-test speed of 10.0 mm/second. 20 mm thick sections were cut out of the middle of 3 different frankfurters per treatment and were used for texture measurements. 20 mm thick bologna slices were used for texture measurements with 3 random measurements were taken on the internal area of the bologna slice.

Sensory Analysis

Hot and cold frankfurters and bologna were evaluated by a trained sensory panel for aroma, off-aroma, cured color, flavor, off-flavor and firmness. Trained panelists (10-12) made up of Iowa State University students and staff, were used for each session. For the cold products, a 12 member sensory panel consisting of Iowa State University students and staff made up the panel. For the sensory panel conducted on hot products, 10 panelists made up the sensory panel. Training included, three, one hour sessions were

initially held using cold (0°C) product from this study. Bologna and frankfurters irradiated at 0 kGy (control) and 2.2 kGy were used to develop descriptive terms for the desired attributes. Frankfurters and bologna were evaluated for bologna/frankfurter aroma, off-aroma, cured bologna/frankfurter color, bologna/frankfurter flavor, off-flavor, and firmness. Three sensory sessions were then held for cold product, one for each replication. Another 1 hour training session was held with the same panelists using products heated up to 71°C prior to sampling for training on heated products. Three sensory sessions were then held for heated product, one for each replication.

Attributes were measured using a line scale (numerical value of 15 units) with graduations from 0 to 15 where 0 represented no aroma, off-aroma, cured color, flavor, off-flavor and not firm while 15 represented intense aroma, off-aroma, cured color, flavor, off-flavor, and firm (Figure 1).

Expectorant cups were provided to prevent taste fatigue and distilled deionized water and unsalted soda crackers were provided to clean the palate between samples. The presentation order was randomized for each session. A computer ballot was constructed and data was collected using a computerized sensory scoring system (COMPUSENSE five, Compusense, Inc. v4.6, Guelph, Ontario, Canada)

Before each session, treatments were randomly assigned a 3 digit code which was then used to present the product to the panelists. Frankfurters for cold samples were prepared immediately upon removal from packaging, cut into 1.9 cm pieces with 1.27 cm pieces from each end being discarded. Three 1.9 cm pieces were immediately placed in covered containers. Bologna for cold samples were prepared immediately upon removal from packaging and cut into 8 triangle shaped pieces per slice of bologna. Four triangle

Please write the 3 number sample code below and answer the following questions about the sample.

Sample number _____

Please rate the sample for each of the following characteristics by placing a vertical mark on the lines below.

OFF-FLAVOR

No off-flavor Intense off-flavor

OFF-ODOR

No off-odor Intense off-odor

COLOR

Light Dark

TENDERNESS

Tender Tough

JUCINESS

Juicy Dry

Figure1: Sensory form used for frankfurter and bologna evaluation.

shaped pieces of sliced bologna were then immediately placed in covered containers. The samples were prepared approximately 15 minutes before being served to panelists.

Sample preparation was the same for hot samples with the exception that after the product was placed in covered containers; the containers were placed in a microwave and heated 30 seconds on high setting. Samples were then allowed to cool approximately 5 minutes before being served to panelists.

Statistical Analysis

Data were analyzed using a 2 x 3 factorial design by factorial analysis of variance (ANOVA) using Proc Mixed of Statistical Analysis Software (SAS) (Version 9.1, Cary, NC). Irradiation and product were the main effects while all sub samples were arranged to give one mean response per replicate and treatment. Separation of means was conducted using LSMEANS and PDIFF when level of significance indicated by ANOVA was $P < 0.05$. A model including the fixed effects of product and irradiation and the product by irradiation interaction was utilized to estimate LSMEANS and to compute standard errors

Results

One of the objectives of this study was to determine if geometric size of products influences quality changes of irradiated RTE meats. Size differences between products were accomplished by stuffing an identical emulsion into large diameter bologna casings and small diameter frankfurter casings. Differences in geometric size are represented in this study as product differences.

The least square (LS) mean values and standard error of the mean (SEM) for moisture, fat, and protein percentages are presented in Table 4. There was no evidence of any irradiation effects on moisture or protein for either bologna or frankfurters. There were product differences between frankfurters and bologna with regard to moisture, fat, and protein composition. Bologna has significantly higher moisture and protein percentages and significantly lower fat percentages than frankfurters. Although significantly different, percent protein and fat in all actuality were not much different. With a SEM of 0.10, any small differences were detected by statistical analysis. The percent moisture being higher in bologna could easily be explained by a higher product yield in bologna compared to frankfurters.

Least square means for pH values are reported in Table 5. There were no differences in either product or due to irradiation. This is expected because the same emulsion was used to produce both products. Least square means for texture measurements are reported in Table 6. Irradiation had no significant effect on texture but frankfurters were significantly more firm than bologna.

Hunterlab was used to objectively measure the internal CIE L* (lightness), a* (redness), and b* (yellowness) characteristics of bologna and frankfurters and the least square means are reported in Table 7. Irradiation had no effect on L* or a* values of either frankfurters or bologna and there was also no significant difference between these two products in either L* or a* values. Frankfurters at 0 dose showed significantly higher ($P < 0.05$) b* values compared to bologna; however, this difference has no important effects at 1.1 kGy dose.

Sensory characteristics were measured using a trained sensory panel on bologna and frankfurters served both cold (Table 8) and hot (Table 9). Products were served at both temperatures because bologna is a product traditionally served cold while frankfurters are traditionally served hot. Because comparing a cold product to a hot product may produce confounding results, both products were served cold and then again served hot. The sensory characteristics measured included bologna/frankfurter aroma, off-aroma, cured color, bologna/frankfurter flavor, off-flavor, and firmness. Irradiation had a significant ($P < 0.05$) impact on all traits measured regardless of temperature and product as reported in Table 10. Although irradiation significantly decreased aroma, flavor and firmness while increasing off-aroma and off-flavor, the dose of irradiation had no effect as product irradiated at 1.1 kGy was statistically the same as product irradiated at 2.2 kGy. Cured color of product was only significantly lower when compared to the control at 2.2 kGy.

TBARS tests were also completed on both cold and hot product to compare off-flavor scores to oxidative rancidity. TBARS values on cold and hot product are reported in Table 11. For both cold and hot product, irradiation and product differences did not affect TBARS values. Temperature increased TBARS values but all were under the threshold of 0.5 to 1.0 of being considered rancid (Tarladgis, Watts, Younathan & Dugan, 1960).

Cold Product

Although not significant ($P = 0.059$), irradiation lowered bologna/frankfurter aroma of cold product. The 0 dose was not different from product irradiated at 1.1 kGy

but was significantly different than product irradiated at 2.2 kGy. Irradiated products were not significantly different. Irradiation had the same effect on bologna and frankfurters.

Irradiation increased off-aroma scores of cold bologna and frankfurters when compared to 0 dose samples; however, there were no differences between different levels of irradiation. Off-aroma increased the same due to irradiation in bologna and frankfurters.

Cured color evaluation was completed on cold frankfurters and bologna slices. Cured color was ranked on a scale ranging from none to intense cured color. Product did not have a significant effect on the cured color of bologna and frankfurters; however, irradiation did have an effect. In frankfurters, samples irradiated at 2.2 kGy had significantly less intense cured color scores when compared to 0 dose samples and frankfurters irradiated at 1.1 kGy. There were no differences in cured color scores between frankfurters irradiated at 1.1 kGy and frankfurters at 0 dose.. Bologna irradiated at 2.2 kGy received significantly lower scores than 0 dose samples but statistically similar scores as bologna irradiated at 1.1 kGy. There was also no difference between 0 dose samples and bologna irradiated at 1.1 kGy.

Flavor and off-flavor scores were not affected by differences in product; however irradiation did significantly lower bologna/frankfurter flavor scores while increasing off-flavor scores. Again, when compared to 0 dose samples, irradiated samples, regardless of dose, received lower flavor scores and higher off-flavor scores from the sensory panel. Cold samples irradiated at 1.1 kGy and 2.2 kGy were not significantly different.

Firmness was measured by the trained sensory panel and was ranked from not firm to firm. Sensory panelists could pick up a difference between products but irradiation had no effect on sensory firmness scores. Frankfurters received significantly higher firmness scores when compared to bologna. Again, this could be explained by the higher yield from large diameter bologna compared to small diameter franks. Bologna has higher moisture percentage in bologna making the product softer than the frankfurter samples with less moisture in them.

Hot Product

For hot bologna and frankfurters, there were product differences in aroma scores, but irradiation did not have a significant effect on the difference in received scores. Bologna had significantly higher aroma scores than frankfurters ($P < 0.05$).

Off-aroma scores were also not significantly effected by irradiation treatment, however there was a trend ($P = 0.057$) for hot frankfurters to receive higher off-aroma scores regardless of irradiation level when compared to hot bologna slices.

Irradiation also had no effect on cured color scores according to the sensory panel, but again there were product differences. Hot frankfurters received ($P < 0.05$) higher cured color scores from the trained sensory panelists when compared to hot bologna. Flavor and off-flavor scores were not significantly affected by either irradiation treatment or product differences when comparing hot product. Off-flavor, however, did show a trend ($P = 0.065$) to be higher in hot product irradiated at 2.2 kGy.

Firmness was significantly affected by both product differences and irradiation level. Irradiated hot product received significantly ($P < 0.05$) lower firmness scores

when compared to the 0 dose samples in both bologna and frankfurters, however, scores were not significantly different between product irradiated at 1.1 kGy and product irradiated at 2.2 kGy. Frankfurters received significantly higher firmness scores when compared to bologna.

Discussion

The differences in texture found between bologna and frankfurters were to be expected. The large diameter bologna retained more moisture during cooking which corresponds to the less firm scores received by sensory panelists and texture analysis. The small diameter frankfurters contained less moisture in the product which led to a more firm product. Irradiation had no effect on the firmness of the products when objective texture measurement was completed or when the two products were served cold. However, when the bologna samples and frankfurter samples were served hot, sensory panelists could pick up a significant difference in firmness between irradiated samples and 0 dose samples. One explanation for this would be that frankfurters contain a protein skin that the panelists could have associated as being more firm than when compared to bologna. With a SEM of only 0.16, there was probably not a real difference in firmness between irradiated frankfurters and bologna when served hot.

Irradiation also had no effect on cured color of bologna and frankfurters when objectively measure with the Hunterlab CIE scores. These results agree with previous studies (Houser, Sebranek & Lonergan, 2003; Houser et al., 2005b; Knight, Miller, Maxim & Keeton, 2007b; Shahidi, Pegg & Shamsuzzaman, 1991; Terrell et al., 1982) which demonstrated irradiation of processed meat products containing nitrite has little

effect on cured meat color. Panelists could not pick up a difference in cured color between products when served cold but could pick up a difference between irradiation levels. The opposite was true when sampling hot products. Panelists could then pick up a difference in cured color between products but not between irradiation levels. With a SEM of 0.09 for cured color of hot product and 0.17 for cured color of cold product, there was probably no real difference observed in cured color by the sensory panel.

Irradiation also had no effect on TBARS values of bologna and frankfurters. This is in agreement with previous studies done on cured pork homogenate (Shahidi et al., 1991) and cured ham and frankfurters (Fu et al., 1995; Houser et al., 2003; Houser et al., 2005b). In these studies irradiation levels ranged from 0.9 kGy to 4.5 kGy and TBARS values did not change throughout storage. This study suggests that low to medium dose irradiation has a limited effect on the lipid oxidation of cured meats. However, if higher irradiation doses were used the results may have been different. Terrell et al. (1981a) reported a dose dependent increase in TBA values for irradiated (0, 8, 32 kGy) pork/beef frankfurters.

When served hot, irradiation had no effect on aroma, off-aroma, flavor, and off-flavor scores of bologna or frankfurters. However, when served hot, frankfurters produced higher off-aroma scores compared to bologna while bologna had a higher aroma score compared to frankfurters. The higher aroma scores received by bologna could be caused by the larger surface area of bologna slices exposed during heating. When served cold, there were no product differences between bologna and frankfurters, however, irradiation decreased aroma and flavor scores while increasing off-aroma and off-flavor scores. These results suggest that irradiation induced quality changes are not

affected by the geometric shape of the product but rather by serving temperature.

Irradiation does not affect flavor, off-flavor or off-aroma of products when served hot.

This could be explained by aroma and flavors existing as volatiles. When products are heated volatiles are flashed off and are no longer contained in the product.

Conclusion

Our results show that irradiation up to 2.2 kGy has no effect on color, oxidation, or texture of vacuum packaged bologna and frankfurters; however sensory results show that aroma/off-aroma and flavor/off-flavor are negatively affected by irradiation regardless of dose. Also, geometric shape does not play a significant role in quality changes of irradiated RTE meats when irradiated at low doses. Serving temperature of product should be considered if irradiation is used in RTE meats.

References

- Association of Official Analytical Chemists. 1990a. Fat (crude) or ether extract in meat. Official method 960.39. In: Official Methods of Analysis. 15th ed. Arlington, VA: AOAC
- AOAC (1990b). Association of Official Analytical Chemists. 1990b. Moisture in meat. Official method 950.46. In: Official Methods of Analysis. 15th ed. Arlington, VA: AOAC.
- AOAC (1993). Association of Official Analytical Chemists. 1993. Crude protein in meat and meat products. Official method 992.15. In: Official Methods of Analysis. 15th ed. Arlington, VA: AOAC
- Centers for Disease Control (March 27, 2008). "Listeriosis." Retrieved September 4, 2008, from http://www.cdc.gov/nczved/dfbmd/disease_listing/listeriosis_gi.html.
- Foong, S. C. C., Gonzalez, G. L., & Dickson, J. S. (2004). Reduction and survival of *Listeria monocytogenes* in ready-to-eat meats after irradiation. *Journal of Food Protection*, 67, 77-82.

Fu, A. H., Sebranek, J. G., & Murano, E. A. (1995). Survival of *Listeria monocytogenes* and *Salmonella typhimurium* and quality attributes of cooked pork chops and cured ham after irradiation. *Journal of Food Science*, 60, 1001-1005.

Gombas, D. E., Chen, Y. H., Clavero, R. S., & Scott, V. N. (2003). Survey of *Listeria monocytogenes* in ready-to-eat foods. *Journal of Food Protection*, 66, 559-569.

Houser, T. A., Sebranek, J. G., & Lonergan, S. M. (2003). Effects of irradiation on properties of cured ham. *Journal of Food Science*, 68, 2362-2365.

Houser, T. A., Sebranek, J. G., Maisonet, W. N., Cordray, J. C., Wiegand, B. R., Ahn, D. U., & Lee, E. J. (2005b). The effects of irradiation at 1.6 kGy on quality characteristics of commercially produced ham and pork frankfurters over extended storage. *Journal of Food Science*, 70, S262-S266.

Knight, T. D., Miller, R., Maxim, J., & Keeton, J. T. (2007b). Sensory and physiochemical characteristics of frankfurters formulated with potassium lactate and sodium diacetate before and after irradiation. *Journal of Food Science*, 72, S112-S118.

Mead, P. S., Slutsker, L., Dietz, V., McCaig, L. F., Bresee, J. S., Shapiro, C., Griffin, P. M., & Tauxe, R. V. (1999). Food-related illness and death in the United States. *Emerging Infectious Diseases*, 5, 607-625.

Shahidi, F., Pegg, R. B., & Shamsuzzaman, K. (1991). Color and oxidative stability of nitrite-free cured meat after gamma-irradiation. *Journal of Food Science*, 56, 1450-1452.

Sommers, C., Fan, X. T., Niemira, B. A., & Sokorai, K. (2003b). Radiation (gamma) resistance and postirradiation growth of *Listeria monocytogenes* suspended in beef bologna containing sodium diacetate and potassium lactate. *Journal of Food Protection*, 66, 2051-2056.

Sommers, C. H., & Thayer, D. W. (2000). Survival of surface-inoculated *Listeria monocytogenes* on commercially available frankfurters following gamma irradiation. *Journal of Food Safety*, 20, 127-137.

Tarladgis, B. G., Watts, B. M., Younathan, M. T., & Dugan, L. (1960). A Distillation Method for the Quantitative Determination of Malonaldehyde in Rancid Foods. *Journal of the American Oil Chemists Society*, 37, 44-48.

Terrell, R. N., Heiligman, F., Smith, G. C., Wierbicki, E., & Carpenter, Z. L. (1981a). Effects of sodium-nitrite, sodium-nitrate and DL, alpha-tocopherol on properties of irradiated frankfurters. *Journal of Food Protection*, 44, 414-&.

Terrell, R. N., Smith, G. C., Heiligman, F., Wierbicki, E., & Carpenter, Z. L. (1981b). Cooked product temperature and curing ingredients affect properties of irradiated frankfurters. *Journal of Food Protection*, 44, 215-219.

Terrell, R. N., Swasdee, R. L., Smith, G. C., Heiligman, F., Wierbicki, E., & Carpenter, Z. L. (1982). Effects of sodium-nitrite, sodium acid pyrophosphate and meat formulation on properties of irradiated frankfurters. *Journal of Food Protection*, 45, 689-694.

United States Department of Agriculture (2003). Verification procedures for the *Listeria monocytogenes* regulation and microbial sampling of ready-to-eat (RTE) products for the FSIS verification testing program. FSIS Directive 10,240.4

Wang, C. H., & Muriana, P. M. (1994). Incidence of *Listeria monocytogenes* in packages of retail franks. *Journal of Food Protection*, 57, 382-386.

Zhu, M. J., Du, M., Cordray, J., & Ahn, D. U. (2005a). Control of *Listeria monocytogenes* contamination in ready-to-eat meat products. *Comprehensive Reviews in Food Science and Food Safety*, 4, 34-42.

Zhu, M. J., Lee, E. J., Mendonca, A., & Ahn, D. U. (2003). Effect of irradiation on the quality of turkey ham during storage. *Meat Science*, 66, 63-68.

Zipser, M. W., & Watts, B. M. (1962). A modified 2-thiobarbituric acid (TBA) method for the determination of malonaldehyde in cured meats. *Food Technology*, 16, 102-104.

Table 4. The effect of irradiation dose on the Least Square Means of product composition on bologna and frankfurters.

Item	Irradiation (kGy)	Product						SEM
		Bologna			Frank			
		0	1.1	2.2	0	1.1	2.2	
Moisture, %		62.40 ^a	62.42 ^a	62.60 ^a	58.19 ^b	58.16 ^b	58.32 ^b	0.10
Fat, %		20.09 ^c	19.98 ^{cd}	19.76 ^d	22.24 ^a	21.87 ^b	21.69 ^b	0.10
Protein, %		38.71 ^a	38.44 ^a	38.61 ^a	36.86 ^b	36.72 ^b	36.73 ^b	0.14

^{a,b,c,d} Means within a row with different letters are significantly different at $P < 0.05$

Table 5. The effect of irradiation dose on the Least Square Means of pH values of bologna and frankfurters.

Product	Irradiation (kGy)	pH values			SEM
		0	1.1	2.2	
Bologna		5.92	5.93	5.93	.01
Franks		5.91	5.92	5.92	.01

Table 6. The effect of irradiation dose on the Least Square Means of texture values of bologna and frankfurters.

Product	Irradiation (kGy)	Texture (g of force)			SEM
		0	1.1	2.2	
Bologna		158.93	150.58	153.97	6.13
Franks		184.09	173.36	168.80	6.13

Table 7. The effect of irradiation dose on the Least Square Means of L* (lightness), a* (redness), and b* (yellowness) values of bologna and frankfurter treatments.

CIE ¹ score	Irradiation (kGy)	Product						SE M
		Bologna			Frank			
		0	1.1	2.2	0	1.1	2.2	
L*		69.12	69.79	69.58	67.99	68.74	68.66	0.58
a*		18.55	18.01	18.01	19.18	18.68	18.32	0.39
b*		15.01 ^{ab}	14.47 ^b	14.61 ^{ab}	15.52 ^a	15.29 ^{ab}	15.15 ^{ab}	0.35

¹ Commission International D'Eclairage L*, a*, b* were L*= lightness, a*= redness, and b*= yellowness on a 0-100 white scale.

^{a,b} Means within a row with different letters are significantly different at $P < 0.05$

Table 8. The effect of irradiation dose on the Least Square Means of Sensory traits of bologna and frankfurter treatments served cold.

Sensory	Irradiation (kGy)	Product						SEM
		Bologna			Frank			
		0	1.1	2.2	0	1.1	2.2	
Aroma		9.54	8.68	8.57	9.44	8.90	8.62	0.34
Off-Aroma		1.05 ^{ab}	2.11 ^a	2.19 ^a	0.68 ^b	1.62 ^{ab}	2.24 ^a	0.42
Cured Color		9.37 ^a	8.84 ^{ab}	8.60 ^b	9.26 ^a	9.22 ^a	8.50 ^b	0.17
Flavor		9.48 ^a	8.71 ^{abc}	8.57 ^{bc}	9.18 ^{ab}	8.28 ^c	8.47 ^{bc}	0.28
Off-Flavor		0.40 ^b	0.85 ^{ab}	1.06 ^{ab}	0.54 ^b	1.05 ^{ab}	1.38 ^a	0.25
Firmness		8.81 ^{ab}	8.05 ^b	8.25 ^b	9.36 ^a	8.80 ^{ab}	8.69 ^{ab}	0.28

^{a,b,c} Means within a row with different letters are significantly different at $P < 0.05$

Table 9. The effect of irradiation dose on the Least Square Means of Sensory traits of bologna and frankfurter treatments served hot.

Sensory	Irradiation (kGy)	Product						SEM
		Bologna			Frank			
		0	1.1	2.2	0	1.1	2.2	
Aroma		9.63 ^a	9.08 ^{ab}	8.35 ^{bc}	8.72 ^{abc}	7.87 ^c	8.45 ^{bc}	0.31
Off-Aroma		0.58 ^b	1.00 ^{ab}	1.53 ^{ab}	1.23 ^{ab}	1.95 ^a	1.81 ^a	0.36
Cured Color		8.98 ^b	8.92 ^b	8.76 ^b	9.55 ^a	9.33 ^a	9.43 ^a	0.09
Flavor		9.32	9.06	8.84	9.26	8.56	8.93	0.31
Off-Flavor		0.62 ^b	0.72 ^b	1.02 ^{ab}	0.60 ^{ab}	1.24 ^b	1.47 ^a	0.24
Firmness		8.15 ^b	7.92 ^{bc}	7.47 ^c	8.91 ^a	8.20 ^b	8.38 ^b	0.16

^{a,b,c} Means within a row with different letters are significantly different at $P < 0.05$

Table 10. Combined data on the effect of irradiation on the Least Square Means (\pm SE) of sensory traits of both bologna and frankfurters served cold and hot.

Item	Irradiation (kGy)			SEM
	0	1.1	2.2	
Sensory				
Aroma	9.33 ^a	8.63 ^b	8.50 ^b	0.19
Off-Aroma	0.88 ^a	1.67 ^b	1.94 ^b	0.24
Cured Color	9.29 ^a	9.08 ^a	8.82 ^b	0.07
Flavor	9.31 ^a	8.65 ^b	8.70 ^b	0.16
Off-Flavor	0.54 ^a	0.96 ^b	1.23 ^b	0.12
Firmness	8.81 ^a	8.24 ^b	8.20 ^b	0.11

^{a,b} Means within a row with different letters are significantly different at $P < 0.05$

Table 11. The effect of irradiation dose on the Least Square Means of TBARS values of bologna and frankfurters served hot and cold.

Item	Irradiation (kGy)	Product						SEM
		Bologna			Frank			
		0	1.1	2.2	0	1.1	2.2	
TBARS ¹		0.12	0.12	0.13	0.13	0.13	0.14	0.01
TBARS ²		0.20	0.20	0.21	0.21	0.23	0.21	0.01

¹ 2-Thiobarbituric acid test on cold product reported as mg malonaldehyde/kg of sample.

² 2-Thiobarbituric acid test on hot product reported as mg malonaldehyde/kg of sample.

CHAPTER 4. GENERAL CONCLUSION

Irradiation processing did not affect color, composition, texture, or promote lipid oxidation in the ready-to-eat (RTE) meats bologna and frankfurters. However, irradiation did alter the aroma and flavor characteristics of these products. Serving temperature of the product also influenced sensory panel scores on aroma, off-aroma, flavor, and off-flavor of product. Irradiated bologna and frankfurters served cold had a decrease in flavor and aroma, but an increase in off-flavors and off-aroma. These irradiation induced quality changes were not present in these same products when served hot. Irradiation dose also did not affect products differently. Irradiation induced quality changes were the same at 2.2 kGy as they were in product irradiated at 1.1 kGy. Also, product size played little difference in quality changes, except in texture where sensory panel found frankfurters to be more firm. This can easily be explained by a higher moisture loss during cooking on small diameter frankfurter links compared to large diameter bologna.

Irradiation processing is an excellent technology for controlling pathogens in RTE meats. However, quality changes that occur as a result of irradiation, including off-flavor and off-aroma development need to be studied further. It was evident in this study that irradiation processing did induce unwanted quality changes by evidence of the sensory panel results. It should not be concluded, however, that consumers find irradiated RTE meats undesirable. The quality changes that occurred may not be picked by the average consumer and irradiation should not be ruled out as a process that could help produce a microbiological safe RTE product in the future. These results indicate that the geometric shape alone does not induce different quality changes in irradiated RTE meats. However,

serving temperature of product may have an effect on consumer's ability to detect off-flavors and off-aromas created by irradiation.

ACKNOWLEDGEMENTS

I would like to start by first thanking Dr. Dennis Olson for giving me the opportunity to study meat science at Iowa State University. Your assistance, advice, and guidance over the last 2 ½ years of school have been invaluable and for this I thank you. I also appreciate the opportunities you allowed me to partake in that did not involve my project. The professional growth I gained from these experiences has been a great benefit to me. I would also like to thank my committee members, Dr. Joe Sebranek and Dr. Aubrey Mendonca, for their time and willingness to help me with my master's program as well as their professional guidance given throughout my time at Iowa State. Your knowledge and support have been greatly appreciated.

I need to give special thanks to the Iowa State Meat Laboratory staff and crew for the help and support they have provided me throughout this project as well as the entire time I have been at the Meat Laboratory. The aid provided during this project covered everything from ordering of raw materials to the irradiation of finished product and clean up, and for that I am very appreciative. Randy Petersohn, Steve Bryant, Jeff Mitchell, Mike Holtzbauer, and Vail Olson: I am especially thankful for all you have done for me and taught me in these past few years as well as answering my endless questions. I also need to thank Deb Michel for your help whenever I needed it these last couple of years. I would have never of been as organized and prepared had it not been for your help.

I am very grateful for the assistance I received from Marcia King-Brink and Elaine Larsen. Their eagerness to help me with laboratory techniques and procedures was very much appreciated. Kathy Hanson and Chris Fedler deserve special thanks for the

organization and hard work put into the sensory panel data. Without all your help the end result of this project would have been very different.

I need to acknowledge my fellow graduate students Brooke McClure, Rachel Smith, Kohl Schrader, Jeff, Sindelar, Jonathon Campbell, Gary Sullivan, Kyle Schulte and Ben Isaacson. Your help and friendship have been very important in the completion of my degree. Thanks to Jeremy Burkett for your help in analyzing my data and your statistical guidance as well as the advice and expertise provided by Mark Anderson. Without your help I would have never been able to complete my project.

Most importantly I want to thank my family. Your endless love and support, regardless of what path I chose to pursue, has meant more to me than you know. I would especially like to thank my parents, Rod and Lori, who have taught me the value of hard work, honesty, and dedication. You have always stressed the importance of education and without you; I would not be where I am at today. Also, I would like to extend a special thanks to my twin brother Brian. Even though I might not show it, your help throughout the last 6 ½ years of college has been much appreciated. Without you, my college experience would not have been as fulfilling. We have always seemed to be able to keep school and work interesting, to say the least. To my brother Travis and my sister Sarah: your support and friendship has meant a lot to me and I consider myself extremely fortunate to have such blessings.